設施園藝研習會專集 148～162 (1989)

熱帶地區番茄水耕系統之改進

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IMPROVEMENT OF HYDROPONIC TOMATO CULTURE SYSTEM FOR THE TROPICS

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Abstract

To improve the noncirculating hydroponic system for tomato culture under tropical conditions, nonaerated, aerated and nutrient capillary technique (NCT) systems were tested in both winter and summer seasons in 1988. Results were obtained as follows.

1. The nonaerated hydroponic system can be applicable to winter season tomato culture, but nutrient solution should be kept at a temperature below 25°C. On the other hand, its potential for tomato culture in summer season was not as great as in the winter season, because of high solution temperature.
2. The nonaerated hydroponic system in tomato culture was improved by aerating the solution, and thus, increasing the physiological activity of roots and uptake of nutrients.
3. The nutrient capillary technique (NCT) system can induce more healthy root growth with vigorous branching than the other two hydroponic systems. Hence, it could be more applicable for tomato culture during summer than the other two systems.

   The smoked rice husks of the NCT system are not only a good rooting medium which permit an adequate oxygen supply but are also very good materials to supply water and nutrients by capillarity.

Introduction

In 1986 AVRDC developed a noncirculating hydroponic system, which requires no aeration, for vegetable production in the humid tropics (Imai 1987). However, utilization of this system is limited in periods of high temperature, because the solubility of O_2 decreases significantly with increasing temperature, whereas plant respiration and, therefore O_2 demand, increases rapidly with increasing temperature. There are two methods to solve the problem of insufficient O_2 in the nutrient solution. One approach is to apply the standard nutrient solution aerating technique in noncirculating hydroponics, i.e. the use of air bubblers which serve to both add and stir O_2 into the nutrient solution. The other method is to employ the nutrient film technique (NFT) in circulating hydroponic systems. On the other hand, in order to avoid the hazard of high temperature in the nutrient solution, the roots and the rooting medium should be kept below 25°C in tomato culture. However, if the standard nutrient solution aerating technique is applied in a noncirculating hydroponic system in the hot tropics, it is very difficult to maintain the solution below 25°C because solution temperature usually increases with the increase of air temperature.

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In an attempt to avoid the hazard of high temperature in solution and stabilize tomato productivity in the tropics, a nutrient capillary technique (NCT) was developed.

Experiments were carried out using tomato plants in two seasons, i.e. in winter and summer 1988 at AVRDC. Three different noncirculating hydroponic systems were compared, i.e. nonaerated, aerated, and nutrient capillary technique (NCT) hydroponics.

Experiment 1. Winter season trial

Materials and Methods

In the winter season trial, 37-day-old tomato seedlings of variety FMTT 6 were transplanted in wooden containers (360 x 60 x 30 cm^3) on 6 January 1988 with two replications in all three different hydroponic systems. Twelve seedlings were transplanted in each container with the spacing 80 x 30 cm^2, and had a population density of 2.2 plant/m^2. The containers were completely covered with white polystyrene foam and black vinyl sheets to cut off solar heat and the development of algae.

The noncirculating hydroponic system previously developed at AVRDC which has no aeration (nonaerated) (Figs. la and lb) was compared with the same system with aeration supplied for 15 minutes per hour (aerated) and the nutrient capillary technique (NCT) using smoked rice husks as a rooting medium to supply nutrients by capillarity from the bottom of the containers. Three layers of sheets were placed in the bottom of the containers with PVC percolating cloth on top, white net (0.15 mm) in the middle, and black net (0.55 mm) at the bottom to prevent roots from developing outside the rooting medium (Fig. 2).

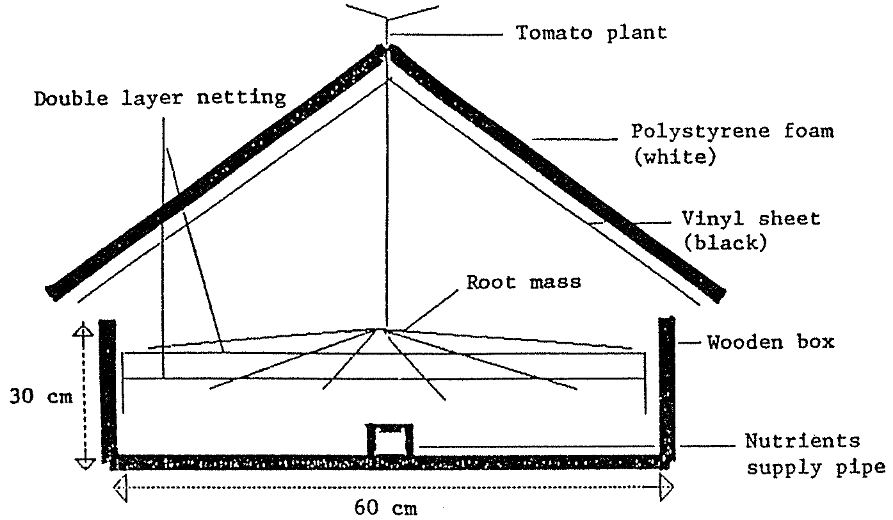

Fig. 1a. Noncirculating hydroponics system.

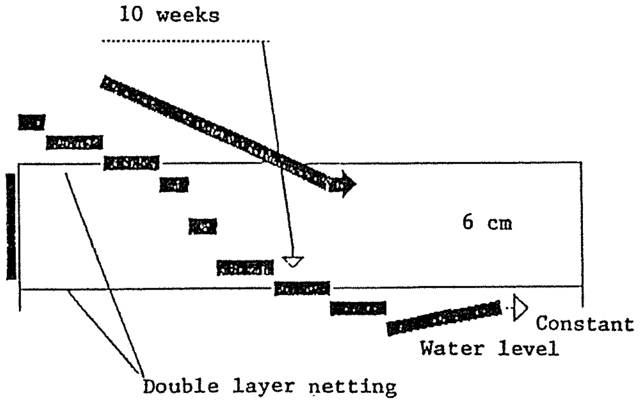

Fig. 1b. The scheme for water level control in hydroponics.

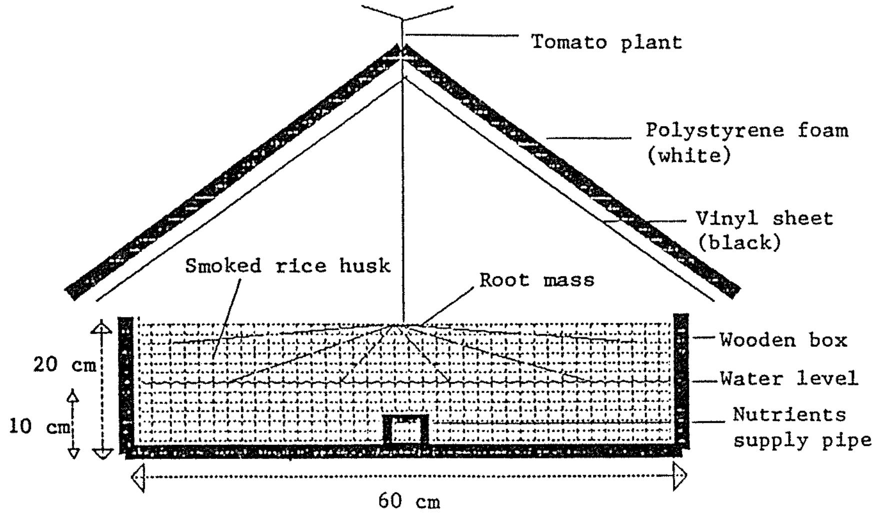

Fig. 2. Nutrient Capillary technique (NCT) hydroponics.

Macronutrients were applied twice a week and micronutrients once every three weeks to adjust solution concentration in accordance with the formula modified from Wilson's for tomatoes grown by NFT (Jones 1983) (Tables la and lb). The solution level was controlled by an automatic device to add tap water.

Table 1a. Macronutrient formula used to grow tomatoes.

Chemical	Vegetative growth stage		Reproductive growth stage	
	(ppm)	(g/l)	(ppm)	(g/l)
$Ca(NO_3)_2 \cdot 4H_2O$	(N)56, (Ca)80	0.472	(N)86, (Ca)123	0.725
KNO_3	(N)48, (K)134	0.347	(N)68, (K)189	0.491
K_2HPO_4	(P)35, (K)78	0.197	(P)50, (K)126	0.281
$MgSO_4 \cdot 7H_2O$	(Mg)48.6	0.493	(Mg)31.0	0.314

Table 1b. Micronutrient formula used to grow tomatoes.

Chemical	Concentration (ppm)	Amount (g/l)
Fe-EDTA($C_{10}H_{12}N_2O_8NaFe \cdot 3H_2O$)	(Fe)3.00	2.2600
$MnSO_4 \cdot H_2O$	(Mn)0.50	0.1540
$CuSO_4 \cdot 5H_2O$	(Cu)0.02	0.0079
$ZnSO_4 \cdot 7H_2O$	(Zn)0.05	0.0220
H_3BO_3	(B)0.50	0.2860
$NaMoO_4 \cdot 2H_2O$	(Mo)0.01	0.0025

Tomato plants were trained to two Y-shape stems with thirteen clusters. The terminal growing points were cut on 5 March 1988. Three fruits were maintained on each cluster. Mature fruits were harvested five times from 25 March to 6 May.

Results

The records of air and solution temperatures during the growth stage in the hydroponic culture are shown in Fig. 3. Pests and diseases were well controlled.

In the winter season, tomatoes in the hydroponic culture, even though nonaerated, grew well. Wilting of the leaves was observed in early February due to low concentration of oxygen in the solution of this hydroponic system. The average maximum air and solution temper-

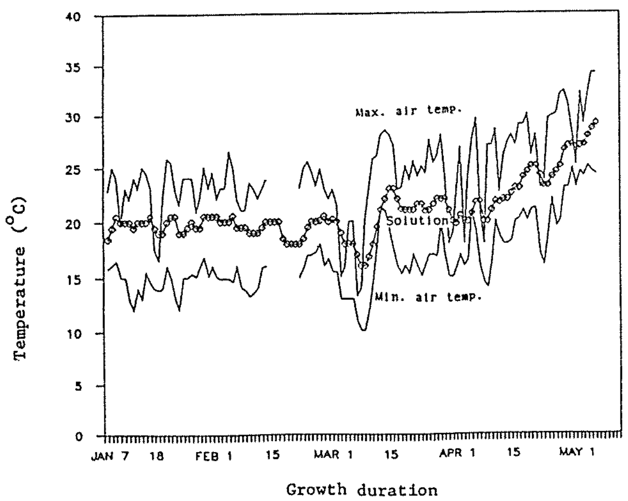

Fig. 3. Changes in air and solution temperatures in noncirculating hydroponic tomato culture in winter 1988.

atures during the growth stage in the winter season were 24.4 and 21.0°C, respectively. During the later growth stage, the solution temperature gradually increased as air temperature increased. Growth of tomato plants in the nonaerated hydroponic culture was retarded compared with that in the aerated or NCT hydroponics systems. This is likely due to the low oxygen concentration in the solution in the nonaerated compared to the aerated culture (Fig. 4). The absorption of water and nutrients in the different hydroponic systems is shown in Figs. 5–9. The uptake of water by plants in the aerated and the NCT hydroponics was much greater than in the nonaerated ones. The same tendency was observed in the uptake of nutrients, such as nitrogen, phosphorus, potassium and calcium.

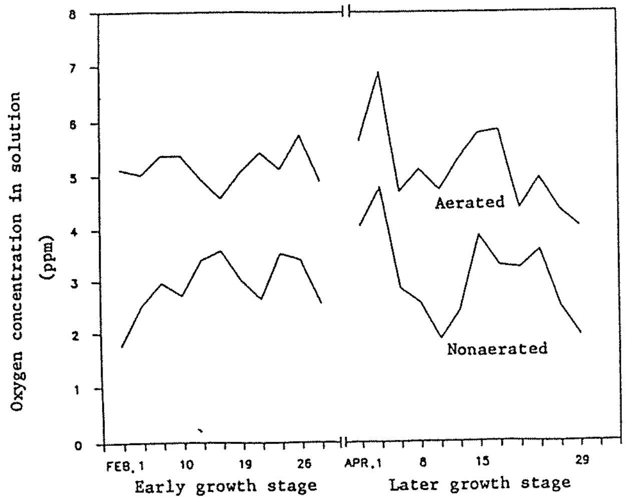

Fig. 4. Effect of aeration on oxygen concentration in nutrient solution of non-circulating hydroponics in winter 1988.

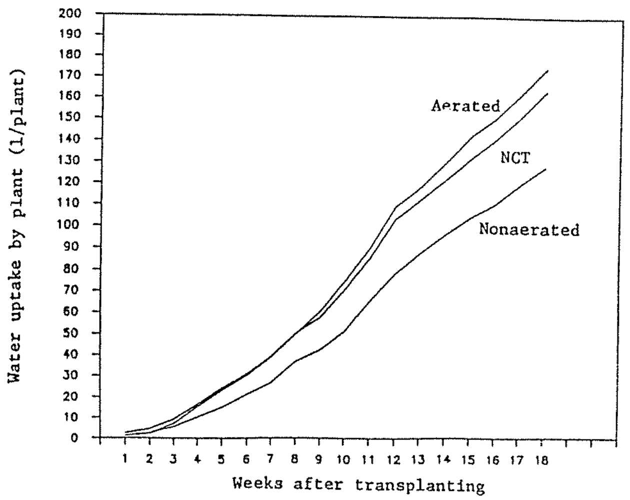

Fig. 5. Water uptake in different hydroponic systems in winter 1988.

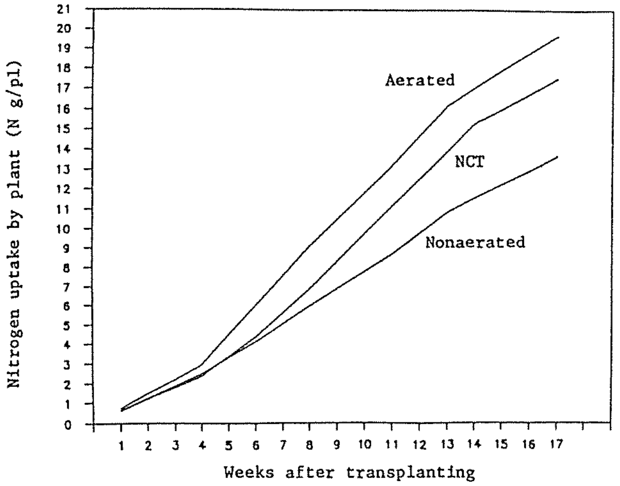

Fig. 6. Nitrogen uptake in different hydroponic system in winter 1988.

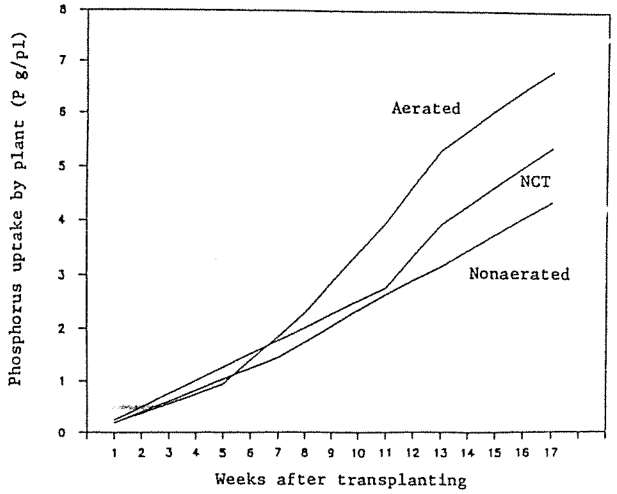

Fig. 7. Phosphorus uptake in different hydroponic systems in winter 1988.

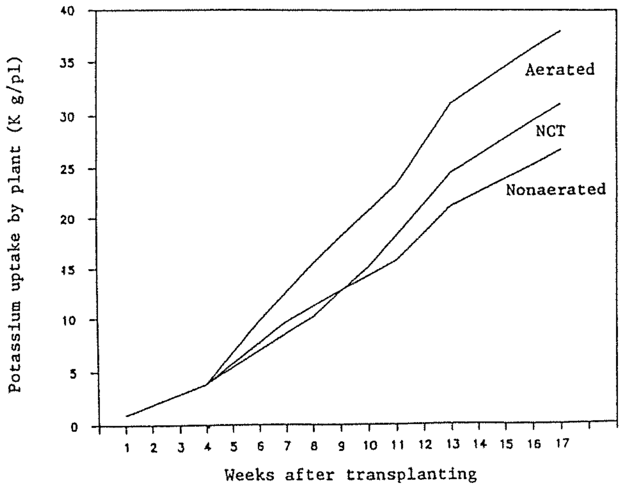

Fig. 8. Potassium uptake in different hydroponic systems in winter 1988.

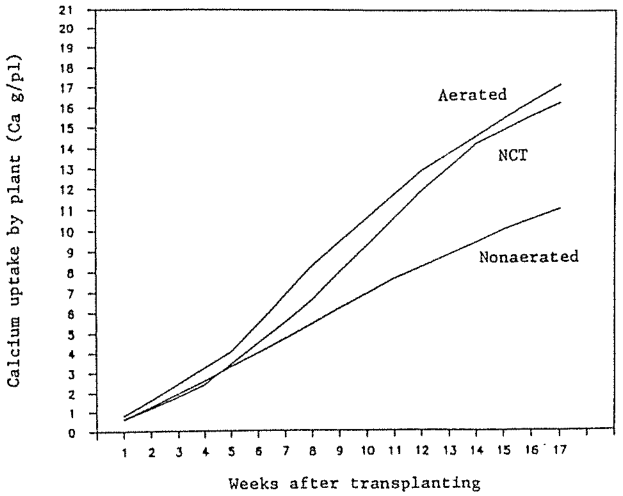

Fig. 9. Calcium uptake in different hydroponic systems in winter 1988.

The physiological activity of roots in the nonaerated hydroponics system at the later growth stage was compared with that in the aerated ones (Table 2). It was clearly observed that root activity in the nonaerated hydroponics was much lower than that of the aerated one at the later growth stage. Tomato yield is provided in Table 3. Fruit yield from the early harvesting during the winter season did not vary much among the three different hydroponic systems, but there was a clear difference in yield during the later harvesting. The much lower yield in the nonaerated hydroponics system is associated with decreasing root activity.

Table 2. Respiratory rate of roots at later growth stage in winter hydroponics 1988.

Hydroponic system	Part of root[z]		
	Aerial	Solution	Total/plant
Nonaerated	2.78[y]	6.23	9.01
Aerated	1.60	27.38	28.98

[z] Measurement of respiratory rate of roots was made by using D.O. meter.

[y] Numerals show O_2 consumption in μl per 1 g of fresh roots.

Table 3. Tomato yield in different hydroponic systems in winter 1988.

Hydroponic system	Factors	Harvesting date					Total
		March 25	April 1	April 8	April 22	May 6	
Nonaerated	Fruit no./plant	3	7	4	8	12	34
	Average fruit weight (g)	230	162	172	158	133	158
	Yield (g/plant)	689	1132	688	1260	1594	5363
Aerated	Fruit no./plant	3	5	5	10	14	37
	Average fruit weight (g)	212	180	213	175	156	176
	Yield (g/plant)	636	899	1064	1746	2178	6522
NCT	Fruit no./plant	3	6	5	8	13	34
	Average fruit weight (g)	230	178	208	171	162	185
	Yield (g/plant)	689	1070	1041	1365	2109	6274

Experiment 2. Summer season trial

The three different hydroponic systems mentioned in the previous trial were examined for adaptability in the summer, 1988 season.

Materials and Methods

After about 29 days of growth, the seedlings (FMTT 6) were transplanted in wooden containers on 17 June 1988. Twenty-four tomato seedlings were transplanted in each container ($360 \times 60 \times 30$ cm^3) with the spacing 40×30 cm^2, and had a population density of 4.4 plant/m^2. They were trained to a single stem, and the top two leaves were cut above the 7th clusters on 1 August 1988. Samples of four plants from each hydroponics system were taken to measure the leaf number and leaf area index on 19 July, 2, 16 and 30 August, and 4 September 1988.

During the second week after transplanting, most top leaves of the plants wilted every noon except the NCT plants. However, they recovered and never wilted again after they were covered with a black-net which reduced the light intensity about 40%. Other cultural methods were the same as in the winter trial.

Results

Tomato growth in the summer was severely retarded compared to the winter because of high air and solution temperatures (Fig. 10). The average maximum air and solution temperatures during the growth stage were 31.2°C and 28.1°C, respectively. The oxygen concentration in the solution was considerably lower (Fig. 11).

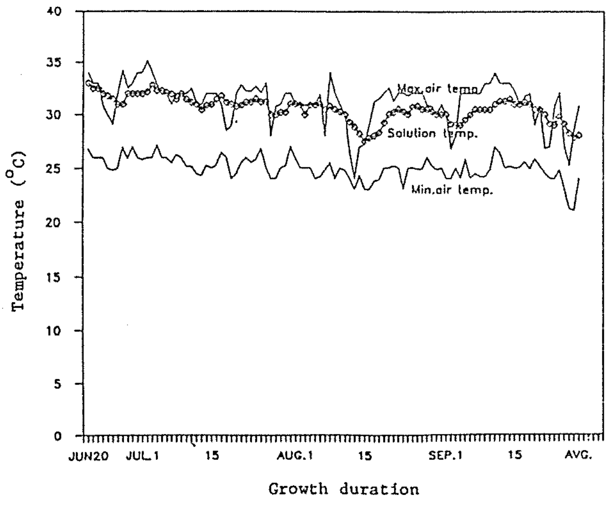

Fig. 10. Changes in air and solution temperature in the noncirculating hydroponics system of tomato culture in summer 1988.

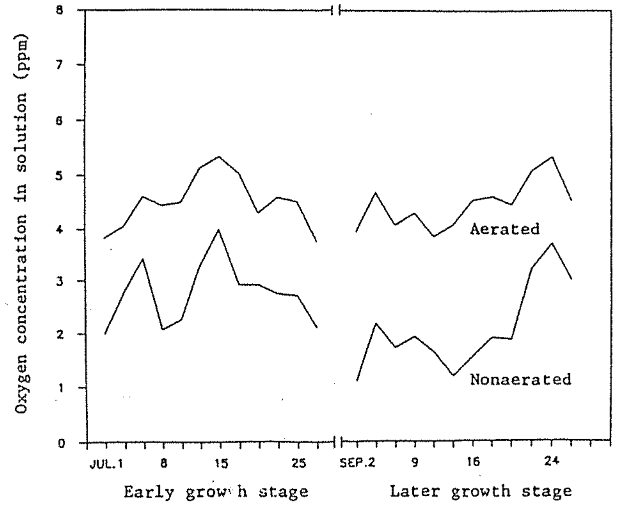

Fig. 11. Effect of aeration on oxygen concentration in solution of the noncirculating hydroponics system in summer 1988.

The number of leaves were greater and the LAI of the plants in the NCT system were larger than those in the other systems during the different growth stages (Table 4). The temperatures in the NCT system were 1.1°C lower than in the other two systems, indicating that the NCT system is better for root activity and favors plant growth during the unfavorable high temperature conditions.

In the nonaerated hydroponics, root rot, associated with low oxygen concentration in the solution, very often occurred to developed roots. The physiological activity of roots during the growth stage was deterred in the nonaerated and aerated hydroponic systems (Fig. 12).

Table 4. The number of leaves and leaf aera index (LAI) at different growth stages in summder 1988^{z}.

Treatment	Date & item:	Jul.19	Aug.2	Aug.16	Aug.30	Sep.4	Average
Aerated	Leaf no.	21.80	26.80	26.30	26.80	27.50	25.80
	LAI	1.73	2.07	1.50	2.50	1.95	1.95
Nonaerated	Leaf no.	21.00	25.50	26.80	26.80	26.80	25.40
	LAI	1.26	1.60	1.52	1.98	2.14	1.70
NCT	Leaf no.	19.80	23.80	24.00	2.65	27.60	24.30
	LAI	1.79	2.44	2.31	3.21	3.29	2.61

^{z}Measured by means of four plants.

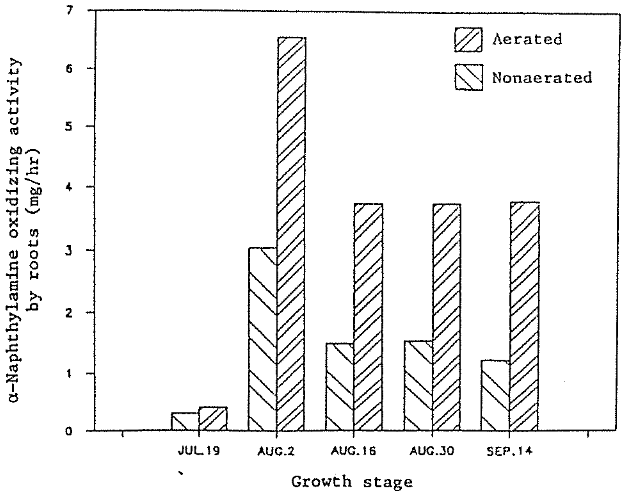

Fig. 12. Effect of aeration in solution on physiological activity of roots in summer hydroponics 1988. (Root activity was measured by using α-naphthylamine—Ota 1970.

In the NCT system, the solution temperature was slightly lower than that in the aerated one (Fig. 13). Roots were healthy and branched well. The tomato yield in the summer season was lower than in the winter season. Among the different hydroponic systems compared, the NCT one has a higher yield with bigger fruit in this season. The nonaerated hydroponics system has a low yield with smaller fruit (Table 5). The uptake of water and nutrients in different hydroponics during the growth stage in the summer is shown in Figs. 14–18. In general, the uptake of water and nutrients in the summer season was lower than in the winter season. The uptake of nutrients was very low, especially in the nonaerated hydroponics because of low root activity.

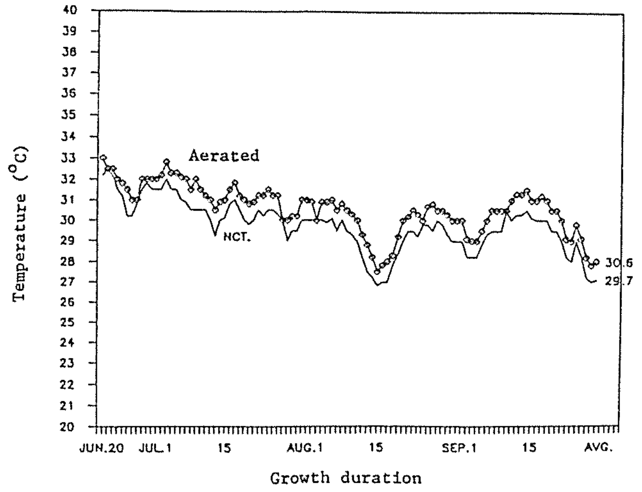

Fig. 13. The solution temperature in the nonaerated and NCT hydroponic systems.

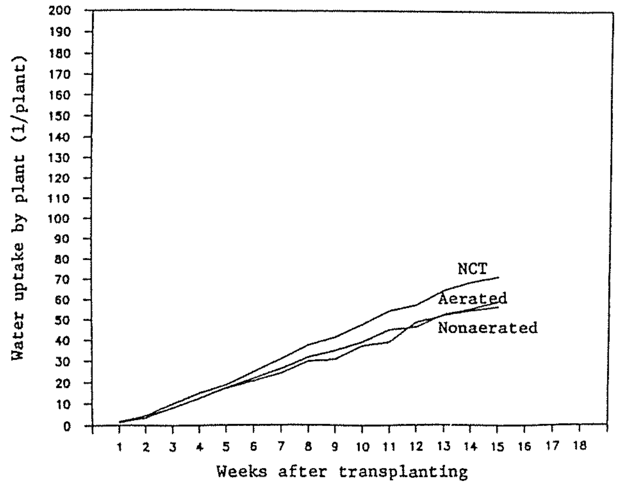

Fig. 14. Water uptake in different noncirculating hydroponic systems in summer 1988.

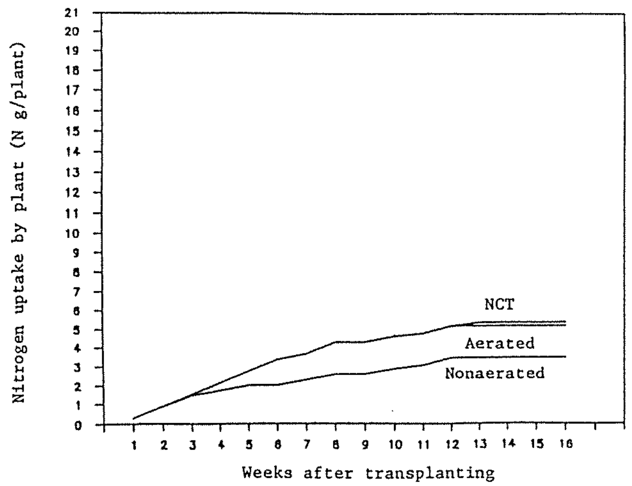

Fig. 15. Nitrogen uptake in different noncirculating hydroponic systems in summer 1988.

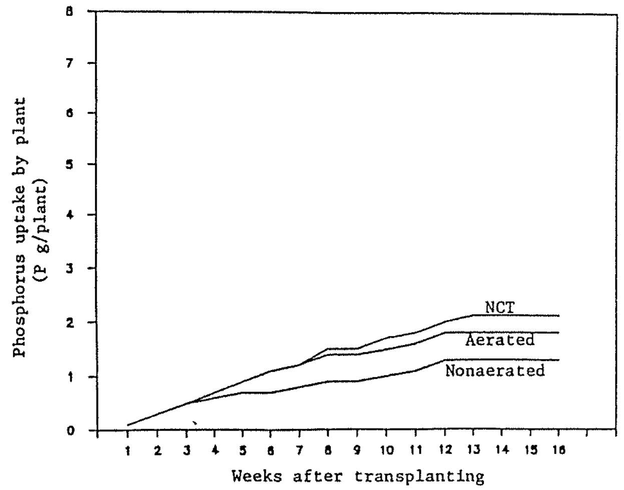

Fig. 16. Phosphorus uptake in different hydroponic systems in summer 1988.

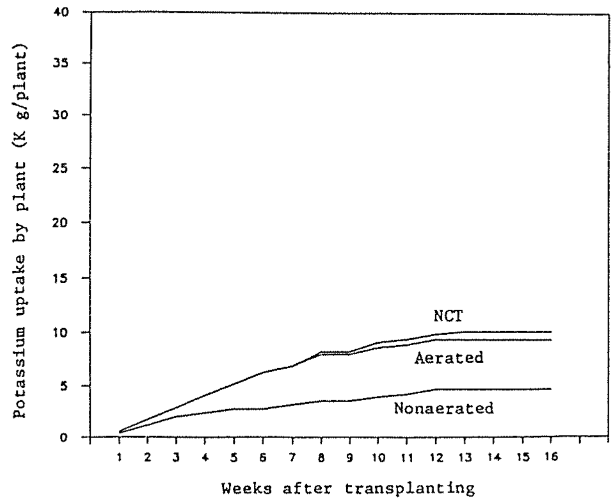

Fig. 17. Potassium uptake in different hydroponic systems in summer 1988.

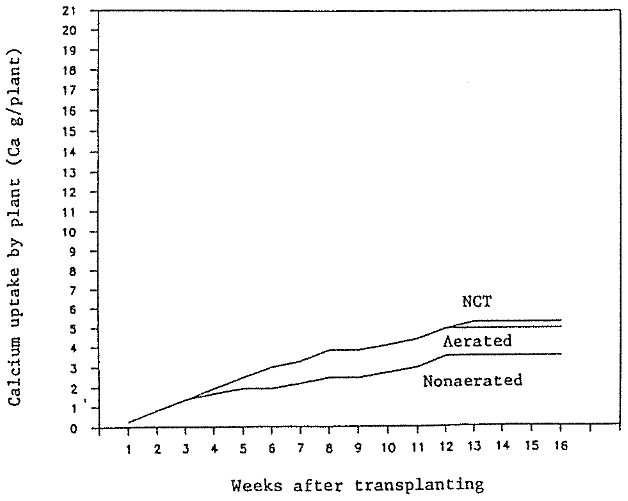

Fig. 18. Calcium uptake in different hydroponic systems in summer 1988.

Discussion

In the summer, the NCT system had a higher yield (Table 5) and a larger leaf area (Table 4) at different growth stages than the other two systems.

Table 5. Tomato yield in different hydroponic systems in summer 1988.

Hydroponic system		Harvesting date								Total
		Aug. 6	Aug. 15	Aug. 22	Aug. 29	Sept. 6	Sept. 15	Sept. 23	Sept. 29	
Nonaerated	Fruit no./plant	2.5	2.4	1.0	1.5	1.3	2.3	1.2	0.3	12.5
	Average fruit weight (g)	141.0	115.0	100.0	49.0	87.0	60.0	77.0	60.0	93.0
	Yield (g/plant)	353.0	277.0	100.0	73.0	113.0	138.0	92.0	18.0	1163.0
Aerated	Fruit no./plant	1.9	2.1	1.3	1.6	1.5	2.1	1.6	0.5	12.7
	Average fruit weight (g)	155.0	135.0	138.0	54.0	120.0	96.0	99.0	70.0	112.0
	Yield (g/plant)	294.0	284.0	180.0	87.0	180.0	202.0	159.0	35.0	1421.0
NCT	Fruit no./plant	2.3	2.9	0.2	1.3	2.1	1.3	1.1	1.3	12.5
	Average fruit weight (g)	171.0	186.0	115.0	74.0	124.0	123.0	91.0	67.0	133.0
	Yield (g/plant)	393.0	540.0	23.0	96.0	260.0	160.0	100.0	87.0	1660.0

There are some constraints in developing hydroponic systems in the humid tropics. Figs. 4 and 11 show that nonaerated hydroponics systems had the lowest O_2 content. Whenever oxygen is deficient, the quanitity of water absorbed is insuficient to offset the loss from transpiration and plants consequently wilt. Root rot is caused by high temperature and depletion of oxygen in the solution.

It is clear that the former noncirculating hydroponic system can not be applied to a hot climate season because of root rot. But it can be applicable in some cases in the winter season when the temperature of the solution is maintained at lower than 25°C.

The water management of both the aerated and nonaerated systems (Fig. 1b) were scheduled to decrease 2–3 cm below the root medium at four weeks after transplanting. Therefore, the hot air suppressed the root elongation and sharply decreased the moisture in the rooting media in the summer season. At the same time, the roots could not retain sufficient quantities of water to meet plant requirement.

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討　論

林學正（台南區農業改良場）問：

何謂 NCT ？如何通氣？是否嘗試栽培其他作物？

太田保夫（亞蔬中心）答：

NCT 是炭化稻殼，介質之養液栽培方式。空氣幫浦打氣，以氣泡型式加入，番茄是唯一實驗的作物。

摘　　要

為改良非循環式水耕系統在夏季果菜類生產的效率，並比較溶氧對番茄根系發展及植株生長之影響，在1987年冬季及1988年夏季利用通氣、不通氣及毛管（NCT）等三種不同方式的非循環式水耕，種植番茄所得結果如下：

1.不通氣的水耕系統，在冬季可用來種植番茄，但是培養液的溫度必須保持在25℃以下。在夏季則由於培養液的溫度太高，種植番茄的效果較差。

2.利用培養液通氣的方法來改良非循環式水耕，可以增加根的生理活性，及對養分的吸收。

3.NCT系統較其他二個系統，更能發生健壯的根系，同時側根的分生也較旺盛。NCT的主要優點為，材料費低廉，建造容易，同時植株的生育旺盛，產量較高，為較適宜應用於夏季種植番茄的水耕技術。NCT所用的介質為炭化稻殼，它不僅是良好的發根介質材料，也能適當的供應氧氣，以及藉著毛細管作用提供作物的養分及水分。

利用養液薄膜法（NFT）栽培葉菜類

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摘　　要

傳統上土壤是栽培作物的主要介質，但因其含有各種阻礙作物生長發育的限制因子，而利用養液栽培可突破土壤中肥料因日照及降雨所造成的蒸散及流失，根部因乾濕度變化劇烈，導致水份供應不平衡或氧氣不足，而降低生長速度等缺點。

本場NFT養液栽培乃針對葉菜類而設計，隨著季節溫度的變化，白菜一期18～15天，年產15～18期；葉萵苣一期25～30天，年產12～15期；芹菜一期50～60天，年產6～7期。而土耕法一年僅可採收3～8期，故單位栽培面積的利用可發揮到極點。

養液薄膜法（Nutrient Film Technique）NFT是水耕栽培法的一種，其特點為：1.養液24小時循環流動，不斷供應養分，並增加水的溶氧量。2.栽培床上設計有“液溝”，栽培時不需要儲存養液，藉著1/ 80或1/ 100之斜度，使養液在栽培床上分開成一道一道薄薄的液流，供應作物生長需要。3.設施構造簡單，操作容易，並可修改栽培床的長寬設計適應不同作物的需要。

一、前　　言

NFT基本上乃利用給液泵浦透過EC控制器，將高濃度之原液定量稀釋於養液槽中，再經沉水馬達將養液槽中混合均勻之養液抽送到每一栽培床。栽培床由固著作物之保利龍板及其支持作用之鍍鋅鋁面板與角架以及供養液通過之PE塑膠布所組成。栽培床斜度為1／80，最高處100公分，最低處75公分，寬度為120公分，長度則分22、27公尺兩種。養液經作物吸收後濃度降低，待迴流入二栽培床中間之養液槽後，由濃度控測器探知濃度，透過給液泵浦與EC控制器，將原液放入養液槽，再經沉水馬達將混合均勻之養液抽送到栽培床，如此周而復始，構成一不斷循環流動的栽培系統。

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